IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Introductory Portion

Be it known that I, Laurence M. Hubby, Jr., a citizen of the United States and a resident of Palo Alto, County of Santa Clara, State of California, have invented a new and useful

OPTICAL SYSTEM FOR FULL COLOR, VIDEO PROJECTOR USING SINGLE LIGHT VALVE WITH PLURAL SUB-PIXEL REFLECTORS

of which the following is a specification.

Background of the Invention

1. Field of the Invention

The invention relates generally to optical systems for large screen, video projectors. More specifically, the invention pertains to a full color illumination system for a video projector, in which a single light valve including a plurality of primary color, sub-pixel reflectors, effects the selective illumination of full color pixels on a projector screen.

2. Description of the Prior Art

Existing optical systems for light valve type video projectors typically use a single light source, such as an arc lamp, to provide illumination for the projection screen. The output of the light source is first subjected to color separation, so that individual red, green, and blue beams are produced. The separated color beams are then directed to respective light valves, and the resultant illumination from each of the three light valves is recombined for projection upon a screen. The optics used to accomplish the color separation, the information modulation of each color beam by the plural light valves, and the recombination of the three beams can be complex and expensive to implement. Moreover, owing to the additional components required for multiple light valve systems, they remain inefficient, in terms of the intensity of the light transmitted through the system and ultimately projected onto the screen.

Consequently, the need exists for an optical illumination system which is simple, yet efficient, in producing a full color image for a video projection system.

The need also exists for an optical illumination system which uses only a single light valve to control the three primary color beams used in a video projection system.

The need also exists for a single light valve optical system which is inexpensive to manufacture, yet provides luminance and image quality comparable to that provided by more expensive three light valve systems.

Summary Of The Invention

The full color video projector system of the present invention uses a conventional light source, in combination with a plurality of splayed, dichroic reflectors, a lenticular lens array, a relay optic, a single micro-mirror, light valve having a plurality of sub-pixel reflectors, a projection lens, and a projection screen.

The light source preferably has a full spectrum output, such as that provided either by an arc lamp, or by a plurality of light emitting diodes, or by a plurality of laser beam generators. The output of the light source is converged, as it passes through a condenser lens. The converged light beam is directed in a first direction toward an array of red, green, and blue dichroic reflective, color filters. The color filters are arranged in splayed relation, with small, equal angles, between the planes of adjacent filters. These filters selectively reflect one color, and pass the remaining portion of the light spectrum. This arrangement permutes the incoming full spectrum light beam, so that three separate and slightly converging beams are produced, each beam corresponding in wavelength to the red, green, and blue primary colors. These reflective color filters also redirect the three beams, so they are now generally headed in a second direction.

The condenser lens focuses the reflected and redirected three primary color beams through a transversely positioned, lenticular lens array. This array is comprised of a plurality of elongated cylinder lenses, arranged in parallel, co-planar relation. The lenticular array produces a repetitive, illumination pattern of three primary color stripes, focused downstream at a focal plane.

An aperture, farther downstream, blocks laterally diverging portions of the illuminating beam, so the acceptance angle of downstream optics will not be exceeded. By eliminating this extraneous light, a high contrast in the projected image is maintained.

The illuminating beam is again focused by a downstream relay optic. The relay optic also redirects the pattern in a third direction, upon a single, micro-mirror light valve. The relay optic is positioned between the focal plane and the light valve, to provide a one-to-one ratio between the original illuminating pattern and the pattern relayed upon the light valve.

The light valve includes a plurality of full-color screen pixels. The pixels are arranged in rows and columns which correspond to the size, configuration, and order of the color strip illumination pattern outputted by the lenticular array. Each of the full-color pixels includes three sub-pixel, micro-mirror

reflectors. Each sub-pixel within a full-color pixel is dedicated to reflecting either red, green, or blue incident beams.

Light valve address circuitry actuates appropriate sub-pixels to reflect incident light energy, either in a fourth direction or a fifth direction, in accordance with corresponding video image information. If a sub-pixel is actuated, the incident light energy is reflected in the fourth direction to a projection lens. The projection lens then focuses this illuminating sub-pixel upon a projection screen. If a sub-pixel is not actuated, the incident light energy is reflected in the fifth direction, away from the projection lens and the screen.

Brief Description of the Drawings

Figure 1 is a diagrammatic view of the major components of optical system of the present invention, showing representative groupings of light beams as they are generated, permuted, focused, and modulated as they pass through the system;

Figure 2 is a top plan view of the lenticular array, taken to an expanded scale, showing the downstream focal plane in which the illumination pattern of primary colors lies;

Figure 3 is a diagrammatic view of a region immediately downstream from the focal plane, showing how lateral portions of the color beams are selectively blocked by an aperture;

Figure 4 is a front elevational view taken on the line 4-4 in Figure 1, showing the repetitive pattern of groups of three color stripes, each stripe corresponding a respective one of the primary colors, present in the focal plane downstream from the lenticular array; and,

Figure 5 is a front elevational view of the light valve and associated control and drive circuitry, the light valve including a plurality of pixels, with each pixel comprised of three sub-pixel, micro-mirror reflectors.

Detailed Description of the Preferred Embodiment

Turning now to Figure 1, the optical system 11 of the present invention uses a light source 12, preferably having a full spectrum output. Light source 12 may be an arc lamp, as shown, or any other equivalent illuminator. Examples would include a plurality of light emitting diodes, or an appropriate combination of laser beam generators. The output beam of the light source passes in a first direction through a light integrator 20. The purpose of integrator 20 is to disperse the output of source 12, so it is substantially the same in intensity across the entire width of the beam. This integrator may be of conventional design, such as that manufactured by the Epson Corporation of Japan, and which is used in the Epson PowerLite 5000 or 7000 Series, Multi-Media Projectors.

The output of the integrator 20 is then focused in the same first direction by a condenser lens 13. The focused light wave output 15 encounters a splayed reflector array 14, comprised of a blue dichroic reflective filter 16, a green dichroic reflective filter 17, and a red dichroic reflective filter 18. As shown in Figure 1, the red filter 18, reflects a red light beam 19, but passes a green light beam 21 and a blue light beam 22. The green filter 17 reflects at least the green light beam 21, but passes the blue light beam 22. The blue filter 16 reflects at least the blue light beam 22, but it may be a full spectrum reflector as well. As will become more apparent herein, the particular order of these beams is entirely arbitrary, and it is only necessary that downstream components be correspondingly ordered for the optical system to operate properly.

The dichroic reflective filters are splayed apart a small, predetermined separation angle 23, to produce a plurality of discrete color beams, each one of a primary color, propagating at the same angle with respect to the adjacent primary color beam. Generally, the angular interval between these beams should be the same, and the angle should be approximately 1/nth of the acceptance angle of downstream optics, where n is the number of primary colors.

Dichroic reflective filters are preferred for this application because they selectively pass and reflect particular wavelengths based upon interference, rather than by absorption. This increases the overall light output efficiency of the optical system herein. Suitable dichroic reflective filters are manufactured by OCLI Inc., of Santa Rosa, California, under the product designation "Colorband Color Separation Filters.".

The separate and converging, red, green, and blue primary color beams impinge upon a lenticular array 24. Lenticular array 24 is comprised of a transparent substrate 26, upon which a plurality of elongated cylinder lenses 27 is arranged in parallel, co-planar relation. For purposes of clarity, only a representative number of lenses 27 is shown in the drawings. A practical system would have many more such lenses, consistent with the resolution requirements for the system.

Cylinders 27 have a focal length 28, such that the incident red, green and blue primary color beams are focused to form corresponding and repetitive, striped color patterns. As shown in Figure 4, these patterns appear as red stripes 29, green stripes 31, and blue stripes 32, all lying in an illumination stripe focal plane 33. The resultant repetitive pattern of primary color stripes is best appreciated in Figure 4, which represents a front elevational view of the stripe focal plane 33. These same stripes are identified in Figure 2, by the letters B, G, and R, corresponding to blue, green and red stripes. It should be noted that having passed through the lenticular array 24, the order of the beams within each primary color beam grouping is now reversed.

The optical characteristics of the lenticular array 24 must cooperate with the optics of the upstream components, so as to produce illumination stripes in the focal plane, which are sized to be nearly contingent, with little or no darkened zone between adjacent stripes. It is fundamental that there will be a finite width to each color stripe produced in the focal plane of the array, owing to the angular spread characteristic of the light source. However, because each lens 27 must concurrently pass the three primary

colors in physically separated fashion, an unavoidable result is that the light is also spread out over three times the angle necessary to pass a monochromatic beam. This is to be contrasted to the operation of the prior art systems, which need only pass one monochromatic beam at a time, through the use of a color wheel or other sequential light frequency illuminator.

This angular spread of the striped illumination pattern presents unique implementation requirements for the optical components downstream from the lenticular array 24. For example, the present system 11 employs a relay optic 34, a micro-mirror light valve 36, and a projection lens 37, all downstream from array 24. The acceptance half-angle of the relay optics is preferably chosen to match that of the projection lens 37. Light which falls outside this acceptance half-angle will not be passed through the system to the projected image owing to an optical stop within the system. In the present system, a first optical stop 38 is provided for that purpose, within the projection lens 37. As a further implementation requirement, where the projection system, as here, uses micro-mirror light valve, the maximum value for the acceptance half-angle cannot exceed the range of motion of the micro-mirrors.

To address these issues, the present system employs an second optical stop 39, interposed between the lenticular array 24 and the relay optic 34. Second stop 39 includes an aperture 41 sized for the passage of only certain portions of the illumination outputted from the lenticular array 24. As shown most clearly in Figure 3, aperture 41 passes the left-hand, 1/3 portion of the red beams 19, the center 1/3 portion of the green beams 21, and the right-hand, 1/3 portion of the blue beams 22. The remaining portions of the beams are blocked by the stop 39, and are thereby prevented from passing through the downstream optical components. Although this results in a loss of 2/3 of the output of the lenticular array, the net output is the same as that for a single color system using a color wheel.

Returning now to Figure 1, the incident composite of the color stripe illumination outputted by the lenticular array 24 is redirected in a third direction and focused by the relay optic 34 upon the single, micro-mirror light valve 36. Although the relay optic 34 shown in Figure 1 contains at least one reflective element, any type of imaging optics may be used, such as refractive, diffractive, or combinations thereof. A characteristic of the relay optic is that it images the stripes in the focus plane 33 onto the plane of the light valve 36 in a 1:1 ratio, in reversed relation, As will be explained in more detail below, the use of this ratio ensures that the color stripes produced by the lenticular lens are properly aligned with corresponding reflective elements within the light valve 36.

The light valve 36 includes a plurality of full-color screen pixels 42, arranged either in rows or in columnar stripes, depending upon the orientation of the components of the optical system 11. The screen pixels 42 in the preferred embodiment shown in Figure 5 are arranged in parallel, vertical stripes. Each screen pixel 42 includes a red sub-pixel 43, a green sub-pixel 44, and a blue sub-pixel 46.

The sub-pixels 43, 44, and 46 are generally rectangular in configuration, and sized so that when three sub-pixels are grouped side-to-side, it results in a square shape for the corresponding screen pixel 42. Furthermore, these sub-pixels are sized, configured, and ordered, so they correspond exactly to the color stripe illumination outputted by the lenticular array 24. And, the overall shape and dimensions of the light valve 36 correspond closely to that of the color stripe pattern at the focal plane 33, as well.

As a result of the identity between the physical attributes of the color stripe illumination pattern and the screen pixel and sub-pixel arrangement in the light valve 36, there is perfect alignment and correspondence between the color stripes and the respective color sub-pixels in the light valve. As will be explained below, this correspondence ensures that the stripe image displayed on the light valve 36 will be appropriately modulated from the full color image information provided to each of the sub-pixels.

As shown in Figure 5, a light valve controller 47 is connected to a column driver 48 and a row driver 49. Each micro-mirror sub-pixel has two electrical connections. Column drive lines 51 are provided, to contact one of these two connections, for every sub-pixel in each respective column. Similarly, row drive lines 52 extend from row driver 49, to interconnect to the other of the two connections for every sub-pixel. In response to video data, the light valve controller 47 actuates a particular sub-pixel by energizing the single row and the single column drive lines which contact the selected sub-pixel. All of the sub-pixels in the light valve are addressed and "refreshed", by continuously stepping through the rows and columns with energizing signals. Typically, the addressing circuitry contains row and column drive circuitry which incorporates memory, allowing the addressing to be completed a row or column at a time, in order to speed up the "refresh" operation. In this manner, the pixels receiving illumination of a given primary color are properly driven by the light valve controller 48 so that the correct image information will be reflected from each pixel.

Light valve 36 may include any type of micro-mirror construction, such as those which operate by means of electrostatic forces, or upon forces generated by energized piezoelectric material. The construction and operation of such micro-mirror light valves, usable in practicing the present invention, are well known to those of ordinary skill in the art, and need not be described in great detail herein. For example, one type of micro-mirror light valve is taught in U.S. Patent Nos. 4,615,595 and 5,061,049, assigned to Texas Instruments Incorporated, of Dallas, Texas. The '595 and '049 Patents describe electrostatically deflected micro-mirrors in a spatial light modulator. A second type of spatial light valve or modulator, showing micro-mirrors suspended by torsion hinges and deflected by electrostatic forces, is disclosed in U.S. Patent No. 5,835,256, assigned to Reflectivity, Inc. of Palo Alto, California. Yet another

type of light valve, employing reflective surfaces deformable by excited piezoelectric crystals, is shown in U.S. Patent No. 5,126,836, assigned to Aura Systems, Inc. of El Segundo, California.

Irrespective of the particular mechanism for moving, deflecting, or reorienting its micro-mirrors, each light valve or light modulator works in generally the same manner. Each of the movable micro-mirrors is capable of selectively reflecting, and thereby modulating, incident illumination. Each micro-mirror has a first state, or orientation, and a second state or orientation. Typically, the difference in angular orientation of the micro-mirror, between the first and second states, is in the range of 10 to 20 degrees. In the first state, usually referred to as the "ON" state, the actuated micro-mirror reflects light beams in a fourth direction, in this case toward an input port 53 of the projection lens 37. Thereafter, the light beams pass through the optical stop 38, and are focused upon a projection screen 54 to produce the illuminated portion of a video image.

In the second state of the micro-mirror, termed the "OFF" state, selected light beams are reflected from one or more sub-pixels of the light valve 36 in a fifth direction, so they will not impinge upon the projection screen. The broken line representation of the color beams represented by the numeral 56, shows the general orientation of the beams when they are headed in the fifth direction. With the beam or beams so deflected, the corresponding sub-pixel area on the projection screen remains dark, until such time as the respective sub-pixel is again actuated. The combination of the illuminated and the dark sub-pixel areas on the projection screen produces the composite video image.

It will be appreciated then, that I have described an improved optical system for a full color video projector. I have also described a light valve construction including a plurality of full color pixels, each pixel having separate red, green, and blue sub-pixel reflectors. The optical system herein including the single light valve construction, exhibits image resolution and brightness comparable to that provided by more complex and more costly prior art systems.